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THE MANY FACES OF ACTIVATED CARBON

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ABSTRACT

Raw materials containing a high percentage of carbon can be processed and converted to activated carbon which has a large surface area. It is this structure that provides activated carbon with the ability to absorb gases and vapors from gases, and dissolved or dispersed substances from liquids. This unique nature of the activated carbon makes it possible for the carbon to be used for purification purposes and also other applications.

INTRODUCTION

Carbon like iron, copper, oxygen and many other materials is an element. It can occur in compounds together which other elements. Even on its own, carbon takes many forms. The best known forms of carbon are solid fuels: charcoal, lignite, coal and peat. All these varieties of carbon have wide ranging properties. When used as raw materials and specially processed they can be converted into activated carbon, a product used to make cane sugar white, or to purify and remove unpleasant odours and harmful substances from air and water (Norit, 1991).

Activated carbon is built up from neatly arranged atoms. This is because every atom exerts an attraction on every neighbouring atom. The atoms at the surface of a carbon crystal have no neighbouring atoms on the other side to attract; in their place, they attract other compounds from their surroundings: molecules that cause unwanted colours, odours or tastes, contaminants, hazardous materials etc. This phenomenon is known as adsorption. It can readily be understood that the amount of these materials that carbon can adsorb will increase as the available surface area is increased. A large surface area is essential because only a few small weight of molecules adheres to each square metre of surface. But more than surface area is needed. To provide a means of separation, it is obvious that adsorption must be selective; certain species of molecules should be adsorbed in preference to others.

To provide adequate purification, an adsorbent should be able to take up and hold molecules of the substance to be removed without disturbing other constituents in the system. Moreover no single type of adsorbent surface will be appropriate for all diverse forms of contamination; therefore a variety of adsorbent surfaces should be available to handle the different needs. It so happens that activated carbon can meet many of the diverse needs (Hassler,1974).

The adsorptive properties, which exist in charcoal, can be developed in various forms by appropriate changes in manufacturing processes or by using difeeent types of raw materials. Consequently brands of commercial activated carbon made by dissimilar processes differ in adsorptive characteristics. Some excell for gas masks, others are superior for sugar refining, still others are best for water purification, and so on. Hence, we can quite properly consider that the term activated carbon comprises a family of adsorbents.

ACTIVATION

The secret of increasing the surface area by activation lies in the formation of pores. Countless tiny channels are formed in every particle of activated carbon. Molecules of undesirable compounds can penetrate into these pores where they are adsorbed.

The smallest pores, the micropores are less than one millionth of a millimetre in cross section. Mesopores are about twenty five times larger and macropores are larger still. Even so, a human hair is about two hundreds times wider than the largest pores in a particle of activated carbon. The role played by the various sorts of pores in the adsorption process can be compared with the road plan of a middle sized town. The macropores are the roads in and out of the town where few people live. Little adsorption occurs here. The mesopores are the main streets and the micropores are the residential areas with their countless ways and byways: this is where the lion's share of the adsorbed compounds end up (Norit, 1991). The development of these micro, meso and macropores and as a result, their surface properties will depend upon the extent of the activation process.

Normally two processes are used to make activated carbon. In the first process the raw material is heated up in the absence of air and carbonised. The product of this process is called charcoal - in fact a pure but unactivated carbon. Chaney(1919) and others report that temperatures below 600 ^{o}C are preferable for producing chars suitable for steam activation. However this is not universal (Mogan, 1946). The charcoal is then processed with steam at high temperatures, under stringently controlled conditions. This process is called steam activation and it produces the extensive pore structure that gives activated carbon its enormous adsorption capacity. In the second process the raw material is pretreated with chemicals such as zinc chloride and carbonised. In that process, one part of the source carbonaceous material is mixed with one to 4 parts of zinc chloride solution. After drying the mixture is carbonized at $600^{o}C$ - 700 ^{o}C although temperatures from 400 - 900 ^{o}C have been reported. The finished char, after washing with acid and water has suitable adsorptive capacity for many applications (Hassler, 1974). By controlling the process of carbonization and activation a variety of activated carbons having different pore sizes can be obtained (Science and Technology, 1986).

ACTIVATED CARBON THROUGH THE AGES

The unique properties of activated carbon were not discovered yesterday, not even the day before. The ancient Greeks knew all about them 2,500 years ago. Hippocrates, known as the father of the healing arts, gave a less activated form to his patients (Norit, 1991).

Today we still have medicinal activated carbon - a very highly purified form of activated carbon in capsules which is an efficacious remedy for a whole range of intestinal upsets. Activated carbon, in the form of a dry powder enclosed in a bandage, is applied as dressing for ulcers, suppurating or gangrenous wounds, and other malodorous secretions. A surgical dressing, prepared from regenerated cellulose and 10 to 15 % of activated carbon, is reported to stimulate secretions in wounds; moreover, the dressing absorbs secretions that are not absorbed by cellulose alone. The dressing has been used advantageously in combination with sulfonamides to treat wounds that develop pus; the sulfonamides, when used alone, are inactive when pus is secreted (Hassler, 1974).

In the fifteen century, the wooden barrels used for water storage on board of ships were charred on the inside, to keep the water fresh for longer. The carbon was not actually activated but still had some adsorptive properties. The earliest date at which adsorptive powers were definitely recognised was 1773 when Scheele (Deitz, 1944) described experiments with gases. In 1785, Lowitz called attention to decolorizing effects of charcoal on solutions. A few years later, wood char was employed to purify cane sugar.

Only in the last century, when industrial production began, was a start made with the systematic study of the properties of activated carbon. Activated carbon was found to be an ideal medium for the removal of impurities from gases and liquids, the basis for the purification of all kinds of products. Since then, the number of application of activated carbon have grown widely (Hassler, 1974).

Today, it is almost impossible to think of life without activated carbon - whether we talk about foods, drinks, a whole range of other products or about health care. Some examples: activated carbon is involved in the production of almost every product that contains sugars or sweeteners, to purify either the raw sugar or the sweetener to gurantee a pure end product. Edible oils pressed from oil bearing fruits or seeds, are purified with activated carbon, so that the end products such as cooking fat, margarine or salad oil is pure white or colourless, and free of undesirable odours and tastes.

Activated carbon also plays a leading role in the chemical industry. From the manufacture of soaps and detergents to the production of nylon, activated carbon is essential. Highly purified activated carbon has a vital function in the purification of pharmaceuticals; it is used in dialysis apparatus, to purify the blood of patients suffering from kidney failure or poisoning.

Activated carbon is no longer used just to remove impurities, but also to recover valuable products. The last trace of gold are recovered from their ores using processes in which activated carbon plays an important role. processes were developed to recover gasoline from natural gas, and to extract benzene from manufactured gas. In space flight, activated carbon is used to keep the air in the crew capsule clean and fresh.

New techniques are still being developed. A lot of manufacturing processes use enzymes - extremely complicated subtances of biological origin which makes reactions go faster. Techniques are being developed that make it possible to bond such enzymes or enzyme producing microorganisms to activated carbon (Norit, 1991). Sometimes, as in the manufacture of vinyl chloride, the substance bonded to the carbon plays a part in ensuring that particular chemical reactions occur. This sort of material is called a catalyst. Activated carbon function as a carrier for precious metal catalysts such as platinum and palladium in the manufacture of many products. Also activated carbon is used as a contant catalyst in various reactions of isomerization, polymerization, oxidation, and halogenation.

The shape and size of activated carbon particles can also be important. In the preliminery purification of drinking water for example, it is mixed with powdered activated carbon. 5 - 20 grammes of powdered activated carbon can purify about one thousand litres of water in an hour. however, recent years have witnessed a resurgence of interest in granular antivated carbon in this field arising from successful installations. The reactivation of the spent carbon brings a large reduction in the cost of using granular carbon, and moreover eliminates a disposal problem. In an analysis of the markets for activated carbon, Parry (1961) makes the following observation:

> "It can be said with certainty that water treatment is a continually expanding market for activated carbon. No other chemicals appear to have replaced activated carbon in this traditional market and there do not appear to be any products on the horizon that make significant inroads in the foreseeable future."

In purifying waste water, activated carbon gives nature a helping hand. Most of the contaminants in waste water is broken down biologically by micro-organisms. Toxic contaminants in the water can upset the biology badly, unless the toxins are made harmless through adsorption onto activated carbon. Activated carbon is also used in the purification of industrial process water, cooling water and to run steam turbines. Demineralised water is generally used in these applications to prevent damage to equipment from scale formation. The ion-exchangers used to demineralise the process water are extremely sensitive to organic compounds and are protected by pretreating the water with activated carbon (Norit, 1991).

In the same way that contaminants can be adsorbed from water, harmful substances can be removed from gases by passing them through an activated carbon filter. Activated carbon purifies the air from the storage tanks and pump houses in sewage treatment works, removing hydrogen sulphide and getting rid of the rotten egg smell. Activated carbon is used to purify the air drawn into the air conditioning systems in buildings; thus works of art are protected from airborn contamination in museums, while operating theatres are supplied with completely clean air. The purification and partial recirculation of used (and pre-heated or cooled) air can also save significant amounts of energy. A large market developed for recovery of vapors of organic solvents used in diversed industrial operation: as processing mediums in the manufacture of plastics and explosives; and as agents to apply a product to its intended use as in painting and printing. Many such solvents are volatile and the escape of the vapors into work rooms creates hazards to health, and from fire and explosion. Moreover, the amount of vapor thus vaporized constitutes an appreciable cost and recovery becomes important for economic reasons (Hassler, 1974).

Activated carbon prevents vapours from all kinds of liquid storage tanks from escaping into the air. In a number of countries, cars must be fitted with the so-called ELCD's (Evaporative Loss Control Devices). The ELCD's contain an activated carbon filter which adsorbs the petrol vapours that would otherwise excape through the petrol tank vent.

The carbon used in gas purification filters can often be cleaned; this allows recovery of the materials adsorbed. This is how dry-cleaners not only prevent their cleaning solvents from escaping into the atmosphere, but also recover them.

OTHER FORMS OF USEFULNESS

Many other forms of usefulness for activated carbons are known (Hassler, 1974) as shown in Tables 1.1 and 1.2.

TABLE 1.1

REPORTED USES OF ACTIVATED CARBON FOR PARTIAL OR COMPLETE REMOVAL OF VARIOUS SUBSTANCES AND ALSO IN NUMEROUS REACTIONS (HASSLER, 1974)

Oil from boilers water
Aldehydes from fermented liquids
Mercury compounds from hyposulfites
DDT from water supplies
Soaps from alkali-refined oils
Peroxides from rancid oils
Conradson residue from used crank-case oil
Sulfonated from mineral oils
Tetraethyl lead from gasoline
Hydroxymethylfurfural from sugar syrups
Unsaturates from mineral oils
Bloom from vegetable oils
Staining impurities from dye intermeadiates
Radioactive substances
Separation of antimony from copper sulfate
Decolorizing and deodorizing biochemicals
Fermentation in biological processes
Depolarization by air in dry cells
Dechlorination of water supplies
Isomerization of nonconjugated oils to conjugated forms
Reactions involving halogens
Electro-refining -- electro-winning for the recovery of metals
Galvanizing baths

TABLE 1.2

LESSER KNOWN FORMS OF USEFULNESS FOR ACTIVATED CARBON

Prevention of gum in certain organic liquids
Storage of toxic volatile laboratory reagents
Removal of certain catalyst residues
Removal of substances that shorten effective life of ion exchangers
Reduce formation of sludge in heat-transfer oils
Assist chemical reactions by adsorbing inhibitors
Safen insecticides and fungicides for sensitive foliage
Stabilize esters

CONCLUSION

Activated carbon is an adsorbent which can be used in vapor and gas phase applications as well as in liquid phase applications. The porous structure of the activated carbon plays an important role in the adsorption processes. The two important processes involved in the production of activated carbon are carbonization which is followed by activation.

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